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# Distributed Traffic Control Laws by Combining Traffic Engineering and Quality of Service

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**Abstract:** With the Internet evolved into a global commercial infrastructure, there has been a great demand for new applications of global reach, for which today's Internet protocols cannot adequately support. The real-time applications, have stringent delay and delay jitter requirements, which cannot be adequately supported by today's Internet protocols. As a result, in recent years, a large number of new Internet protocols were developed in an attempt to meet this demand. Multi-Protocol Label Switching (MPLS) has been envisioned as an ideal platform upon which guaranteed services could be developed. Service guarantee is achieved by setting up and managing a set of primary and backup Class-of-Service (CoS) aware label switched paths across an IP domain. In addition to MPLS, this approach requires a suite of protocols be implemented, e.g., DiffServ for Quality of Service (QoS), path protection/fast rerouting for link Failure Recovery (FR) and constraint-based routing for Traffic Engineering (TE). The proposed thesis develops a family of Distributed Traffic Control Laws (DCLs), which allows optimal, multiple CoSs, multipath based rate adaptation and load balancing. The DCLs drive the network to an operation point where a user defined global utility function is maximized. The proposed family of DCLs has, the capability to enable optimal, scalable QoS and Traffic Engineering, simultaneously.

**Key words:** Traffic control, traffic engineering, Multi-Protocol Label Switching (MPLS), Class-of-Service (CoS), DCLs

## INTRODUCTION

The Transport Control Protocol (TCP) window-based congestion control algorithms use minimum information from the network as input to allow fully distributed traffic control. In other words, the only needed feedback information for the TCP window-based congestion control is whether the forwarding path is congested or not.

This allows the TCP source node to infer path congestion by counting the number of repetitive acknowledgments of the same packet or measuring end- to-end round-trip delay, making TCP a truly end-to-end protocol without the assistance of the underlying internetworking layer infrastructure. This has made the proliferation of the Internet applications at global scale possible.

An excellent example is the fast, ubiquitous adoption of World Wide Web due to its use of TCP as its underlying transport. However, as the Internet has evolved into a global commercial infrastructure, there has been a great demand for new applications of global reach, for which today's Internet protocols cannot adequately support.

For example, real-time applications, such as Voice over IP (VoIP) and video phone, have stringent delay and delay jitter requirements, which cannot be adequately supported by today's Internet protocols. As a result, in recent years, a large number of new Internet protocols were developed in an attempt to meet this demand.

For example, Multiprotocol Label Switching (MPLS) has been envisioned as an ideal platform upon which guaranteed services could be developed. Service guarantee is achieved by setting up and managing a set of primary and backup Class-of-Service (CoS) aware label switched paths across an IP domain.

In addition to MPLS, this approach requires a suite of protocols be implemented, e.g., DiffServ for Quality of Service (QoS), path protection/fast rerouting for link Failure Recovery (FR) and constraint-based routing for Traffic Engineering (TE). This, however, means that, to adequately support real-time applications, a whole suite of protocols with significant involvement of the IP core nodes need to be developed.

This raises serious concerns about the scalability and complexity of using these protocols to support real-time applications at a global scale.

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Hence, a key question to be answered is whether it is possible to enable the above service quality features, including QoS.

The existing algorithms focus on TCP types of traffic including both empirical algorithms and algorithms based on control theory (Utkin, 1992). These algorithms assume a single path and the approaches taken are not optimization based.

In the existing scheme, flows with different ingress-egress node pairs share the same network resources. Degree of interaction between different flows due to the resource constraints was very poor in the existing distributed traffic control laws (Bernardo *et al*., 2007).

Since, flows with different ingress-egress node pairs share the same network resources, the key challenge in the design of DCLs is the fact that there is a high degree of interaction between different flows due to the resource constraints. One existing approach to get around this is to incorporate a link congestion cost into the overall utility function, which replaces the link resource constraints. Then, the problem is solved using a gradient type algorithm, resulting in families of DCLs that support point-to-point multipath load balancing for rate adaptive traffic (Elwalid *et al*., 2001; Movsichoff *et al*., 2005).

Some of the existing methods developed a family of DCLs based on nonlinear control theory. This family of DCLs can be applied not only to usual rate adaptive traffic with point-to-point multipath, but also to rate adaptive traffic with minimum service requirements and/or maximum allowed sending rate and to services with targeted rate guarantee, all allowing for point-to-point multipath.

The only needed feedback from the network is the number of congested links along the forwarding paths (Alpcan and Basar, 2003; Chiu and Jain, 1989). Moreover, the technique applies to any utility function that can be expressed as a sum of concave terms.

Due to, the needed use of the number of congested links in a forwarding path as the input to a DCL, the existing family of DCLs requires explicit congestion feedback from the network. The existing scheme can only be applied to a connection-oriented network, such as an MPLS enabled IP network (Sharma and Hellstrand, 2003).

In the proposed system, the DCLs control the traffic independently at different traffic source nodes, e.g., edge nodes or end-hosts. A salient feature of this family of DCLs is that the needed information feedback from the network is minimum, i.e., whether a forwarding path is congested or not, which can be inferred at the source node itself, the same way as TCP congestion notification. This makes it possible to allow this family of DCLs to be operated end-to-end.

## SYSTEM MODEL

The traffic flows can be described by a fluid flow model, where the only resource taken into account is link bandwidth. For simplicity, first restrict ourselves to the point-to-point multipath only and address the point-to-multipoint and multicast cases later.

The system model, considers a computer network where, calls of different types are present. Types denote an aggregate of calls with the same ingress and egress node, as well as service requirements i.e., calls that share a given set of paths connecting the same ingress-egress node pair and whose service requirements are to be satisfied by the aggregate, not by individual calls. When the edge nodes coincide with the end-hosts, the control laws developed in this paper become end-to-end control laws working at the transport layer servicing individual application flows.

**Discretization, delays and quantization:** The issues handled in implementing the control laws implement a discrete time version of the control algorithms, uses finite word length which leads to a quantization of the possible data rate values and there is delay in the propagation of the congestion information. All of these lead to a well-known phenomenon called oscillation. Even in this case, the discretization of the control laws is approximately optimal.

**Congestion detection and notification:** To maintain the transport or higher layers abstraction, a source inferred congestion detection and notification mechanism is desirable for the implementation of this family of DCLs in a connectionless IP network. However, unless the transport or higher layer protocol that implements this family of DCLs is defined, the exact source inferred congestion detection and notification mechanism cannot be decided.

For example, if a DCL in this family is used in association with a TCP-like reliable transport protocol, a source inferred congestion detection and notification mechanism based on, for example, ACK counts can then be adopted. On the other hand, if the DCL is used in association with an UDP-like unreliable transport protocol, the forwarding path congestion may be detected and notified by periodically sending an echo packet to the destination node and measuring the round-trip time of the echoed packet.

The source inferred congestion detection and notification approaches can also be used in the context of a connection-oriented network, such as an MPLS. In addition, other mechanisms can be employed, e.g., mechanisms using a signaling protocol for congestion detection and notification.

**Failure detection and notification:** The node/link failure detection and notification may or may not be integrated with the congestion detection and notification mechanism. Again, they are dependent on the actual protocol that implements an DCL in this family. For example, a source inferred congestion detection and notification using echo packets to infer path congestion may also be used to infer possible node/link failures. On the other hand, in an MPLS network, the path protection mechanism under development can be leveraged to allow failure detection and notification, separate from the congestion detection and notification mechanisms.

**Design parameters:** The behavior of the algorithm under different choices of the design parameters are:

**Oscillation reduction functions:** The adaptive oscillation reduction has a big impact on performance. Considering the behavior for a constant, the maximum value allowed for the time variation. The observed oscillation is clearly larger in magnitude. Moreover, due to the larger oscillations, convergence to a larger neighborhood of the optimal is obtained and departures from the average target rates for AF are also larger (providing a worse service to these users). On the other hand, the transient response is faster due to larger data rate derivatives.

**Discretization step:** Another, parameter that has a bearing in the performance of the algorithm is the discretization step. In order to show its influence, it was chosen as 10 ms. Clearly, oscillations are also larger in this case. However, the response is still acceptable and a smaller could be used to limit the magnitude of the spikes.

**Scaling of the utility function:** The scaling of the utility function does not alter the solution of the optimization problem at hand. It does, however, change the bounds on the quantities. Due to the exponential dependence on the gradient, it is advisable to choose a small value of such that the resulting value of is in the order of 1. Simulations have shown that the algorithm is very sensitive to with the amplitude of the oscillations increasing substantially when one increases this parameter.

However, convergence to a neighborhood of the optimal is still achieved as one can expect. Also, the AF constraints are satisfied in the average but large departures from the imposed average rate can happen for high values.

## EXPERIMENTAL EVALUATION

The new family of DCLs provides the much needed mathematical foundation that allows the use of source inferred congestion detection and notification to maintain layer abstraction. The new family of DCLs allows the rate control to be decoupled from the congestion detection mechanisms in use. This means that any queue management algorithm and queue scheduling discipline used in the core nodes can coexist with the family of DCLs running at the edge nodes or end-hosts.

The implementation of any DCL in this family, only needs to consider the 2 end nodes, provided that a source inferred congestion detection and notification is available. However, having said that, different queue management algorithms and queue scheduling disciplines do have an impact on the overall performance for any end-to-end traffic control mechanism.

As a result, there are 2 key components in the implementation of the family of DCLs, i.e., the implementation of the DCL in the edge nodes or end-hosts and the design of source inferred congestion detection and notification mechanisms. The system model focus on the issues related to the design of source inferred congestion detection and notification mechanisms.

## CONCLUSION

The proposed family of DCLs can be applied to a connectionless IP network to enable sophisticated service quality features, solely based on a set of shortest paths from any given ingress node to a set of egress nodes. The Distributed traffic Control Laws (DCLs) allows optimal, multiple CoSs, multi-path based rate adaptation and load balancing.

The DCLs drive the network to an operation point where a user defined global utility function is maximized. The mathematical formulation allows both point-to-point multi-path and point-to-multipoint multi-path, the family of DCLs can be applied to a connectionless IP network to enable sophisticated service quality features, solely based on a set of shortest paths from any given ingress node to a set of egress nodes.

A core node may be CoS and multipath agnostic and may employ any queue management/scheduling algorithms, e.g., simple FIFO queues, at its output ports. This family of DCLs allows fast time scale TE through multi-path load balancing. The proposed DCLs can automatically repartition the traffic in an optimal way among the rest of the multipaths when path failures occur. The proposed scheme can be applied for both connection oriented and connection less networks.

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